3.27 GHz IIR Notch Filter for the 2-4 GHz Stacktail Momentum Cooling System

Ed Cullerton
RF & Instrumentation / Beams Division

Abstract: *The stacktail momentum cooling system of the Antiproton Accumulator has been upgraded to 2-4 GHz operation. Due to beam pipe dimensions and kicker design, a waveguide transverse resonance at 3.27 GHz has been observed. This resonance causes transverse heating of the core Pbar beam, hence limiting the maximum gain for the stacktail system and ultimately the achievable stacking rate. Historically, there has been a set of transverse kickers in that system to suppress the undesirable transverse kick applied by the longitudinal kickers. In the original 1-2 GHz system, no such resonance was observed allowing cancellation of the transverse kick by utilizing four correction kickers spaced 90 degrees apart in betatron phase advance, two in each horizontal and vertical planes. The new 2-4 GHz system presents a slightly different transverse resonance from each of the eight kicker tanks, making it impossible to cancel the resonance with the four installed kickers. An attempt to understand and eliminate the source of the transverse kick has failed. It has been decided to design a special filter to notch out the narrow resonance from the transfer function. The filter must be narrow and not effect the phase flatness of the rest of the band. For this reason, an Infinite Impulse Response (IIR) filter was chosen.*

Circuit design

The design of the notch filter requires an IIR feedback loop. A diagram of the IIR feedback loop is shown in fig.1. The initial circuit was designed on HP ADS using ideal elements, and the circuit schematic is shown in fig.2a. A delay element of 308 ps is added to the feedback loop to simulate one wavelength at 3.27 GHz. A gain of 5 dB is used on the ideal amplifier to give a gain close to unity for the loop. The response of the circuit is shown in fig.2b.

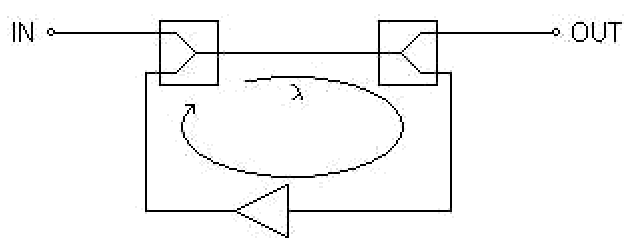

Fig. 1. Circuit diagram of an IIR feedback loop

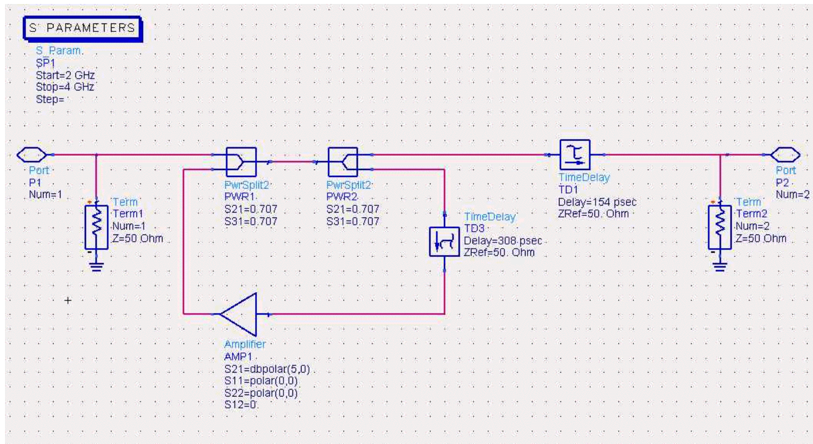

Fig. 2a. HP ADS circuit model of the IIR feedback loop using ideal elements

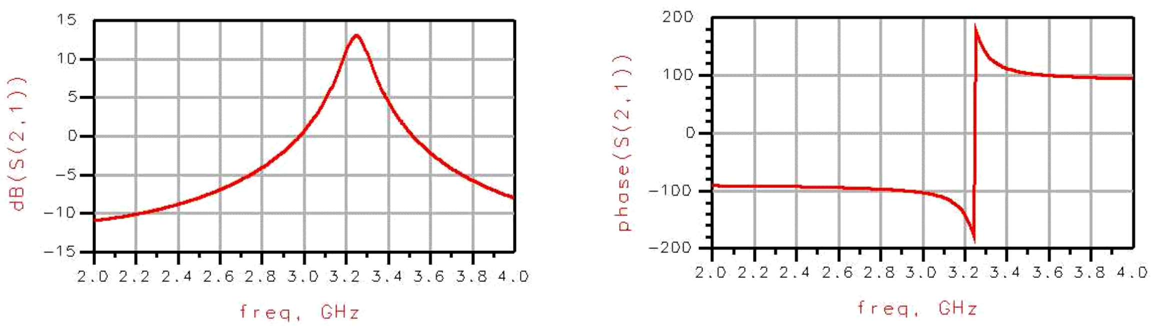

Fig. 2b. Response of the ideal IIR feedback loop

To create a notch filter from this response, a correlator is built. A correlator circuit is added to the IIR feedback loop using elements as shown in fig.3a. The HP ADS ideal circuit model is shown in fig.3b, and the response of the circuit is shown in fig.3c. As seen in the response of the circuit, the phase is near zero before and after the notch. This is the primary reason for choosing the IIR topology for this application.

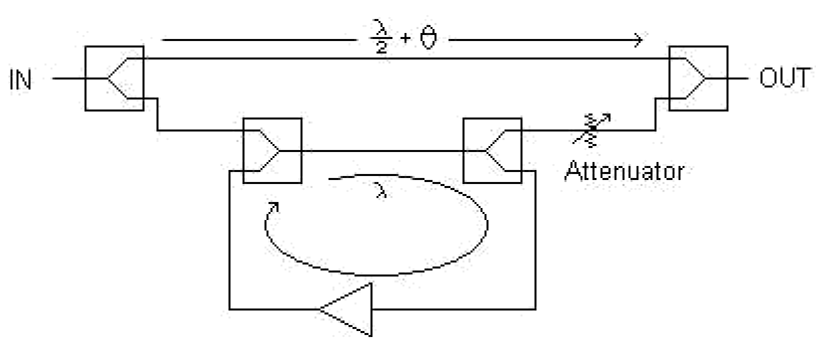

Fig. 3a. Correlator circuit

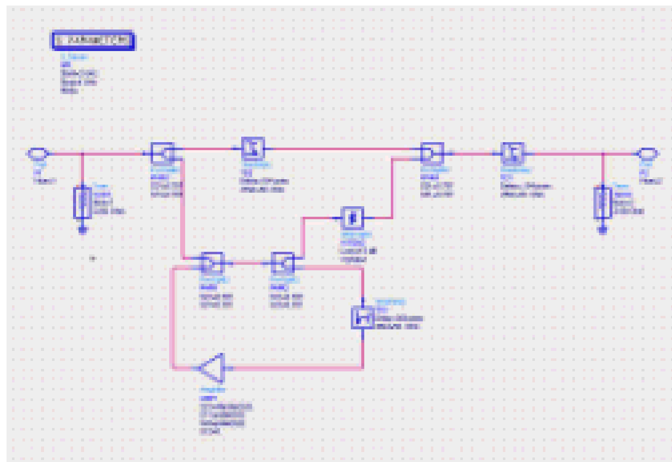

Fig. 3b. HP ADS circuit model using ideal elements

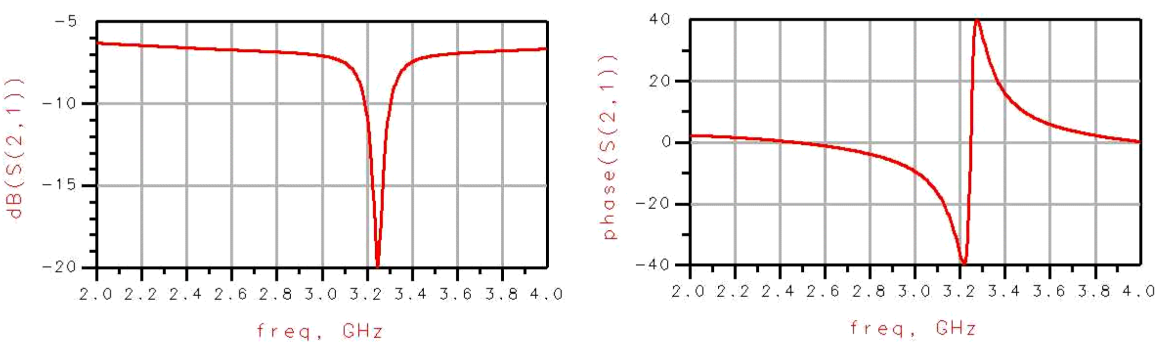

Fig. 3c. Response of the circuit shown in fig.3a

To check the effectiveness of the notch filter in the system, the ideal notch filter is inserted into two transfer functions. The two transfer functions are between the 2-4 GHz stacktail momentum kickers and the 2-4 GHz betatron pickups. Fig.4 shows the transfer functions in blue, and the transfer functions with the ideal notch filter in red.

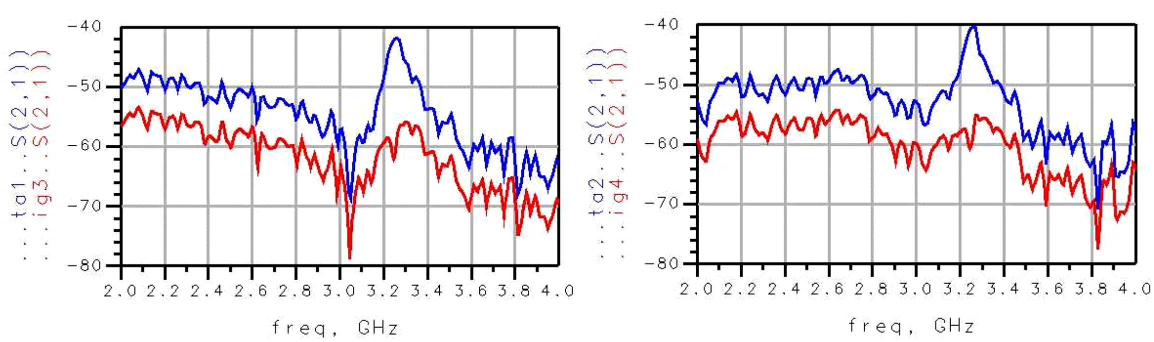

Fig. 4. Transfer functions with ideal notch filter

Circuit layout

The practical circuit design is described in this section. The circuit is fabricated in microstrip form on Arlon 31 mil, 2.33 dielectric substrate. Agilent Technologies MGA-86576 1.5 – 8.0 GHz low noise GaAs MMIC amplifier was chosen for the feedback loop. The MGA-86576 has about 23 dB of gain, and has a +5 volt DC bias on the output. Edge coupled microstrip lines are used to replace the splitter of the feedback loop to avoid DC coupling between the input and output of the amplifier. The coupled lines have about -21 dB of coupling, and is centered at 3 GHz. Wilkinson power splitters are used, and they are designed at 4 GHz due to size constraints on the feedback loop. The attenuators for the correlator are connected on the outside of the circuit board. The delay line for the correlator is also attached on the outside of the circuit board. The delay line is used to provide a phase difference of 180 degrees. Attaching the attenuators and the delay line on the outside allow for easy tuning of the circuit. The circuit layout is shown in fig.5. There are gaps in the microstrip lines at the input and at the 50 ohm termination for DC blocking capacitors. The capacitors are Dielectric Laboratories model C06BL, and the DC bias tee at the output is a Mini-Circuits ZFBT6G.

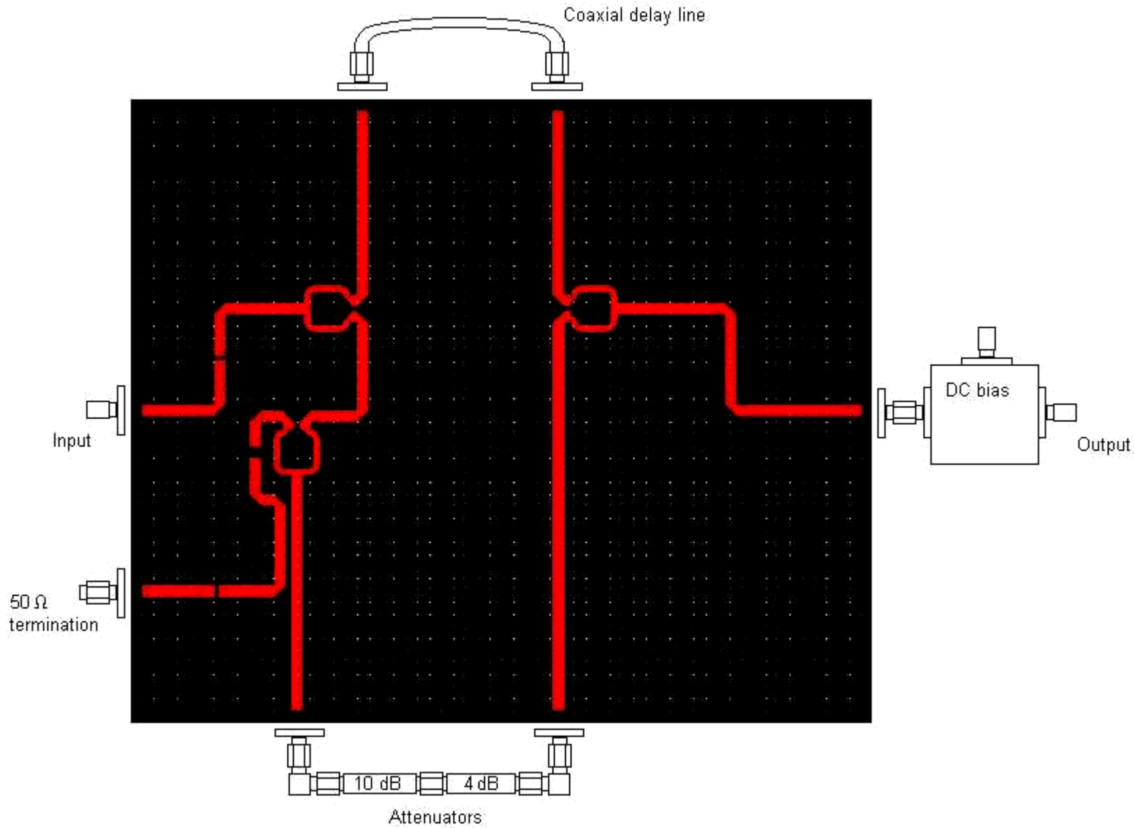

Fig. 5. Microstrip layout of the filter.

Care must be taken when mounting the amplifier to the board. The path to ground must be as short as possible to avoid any added inductance that can change the performance. The diagram in fig.6 shows how the amplifier was mounted to the board.

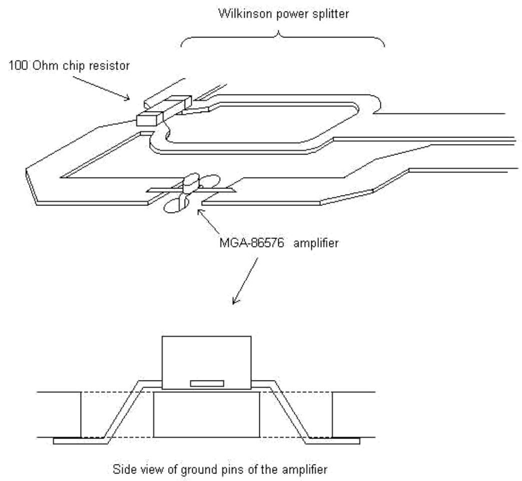

Fig. 6. Detail of the mounting of the amplifier

The measured results versus the simulated ideal filter are shown in fig.7. The ideal simulated results are shown in blue, and the measured results are shown in red. The depth of the notch is slightly less than simulated, but this can be controlled by tuning the DC bias voltage of the amplifier. The DC bias voltage was set to +4.2 Volts for this measurement. Several other things were tuned to get these results. The length of the coaxial cable was tuned, the value of attenuation was adjusted, and the length of the feedback loop was tuned. The length of the coax line is 467 ps, and a 10 dB and a 4 dB attenuator are used for a total of 14 dB of attenuation. The feedback loop was tuned because the notch frequency was a few MHz too high. Trimming off a small amount of the microstrip line had the effect of lengthening the loop and decreasing the notch frequency. A diagram of the trimmed metal in the feedback loop is seen in fig.8.

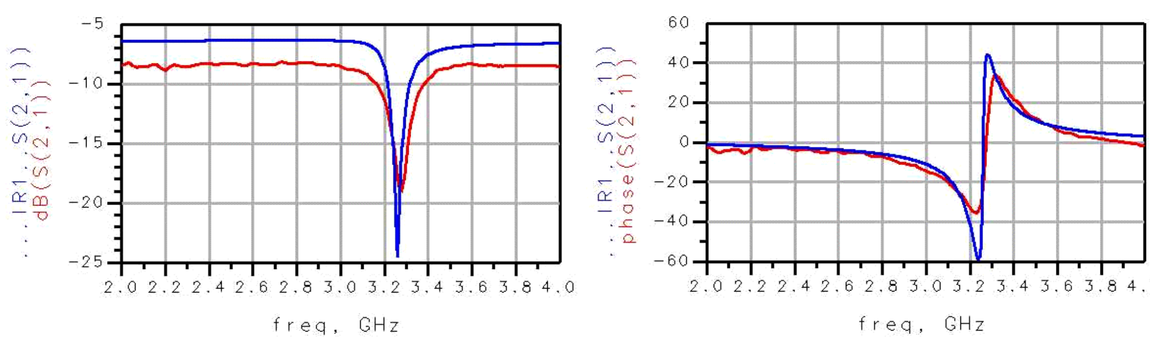

Fig. 7. Measured results of the notch filter versus simulated ideal notch filter.

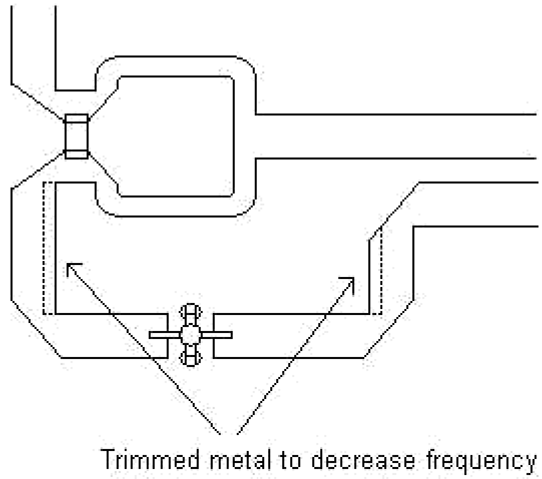

Fig. 8. Trimmed metal in the feedback loop to decrease frequency

A photograph of the filter is shown in fig.9. The cover of the circuit required some absorber material to stabilize the circuit. The cover can be seen in the photograph in fig.10. A layer of G10 material is placed between the metal cover and the absorber material to improve performance and also give mechanical support to the absorber material. The absorber material is ARC technologies DD-10214. The complete assembled circuit is shown in fig.11.

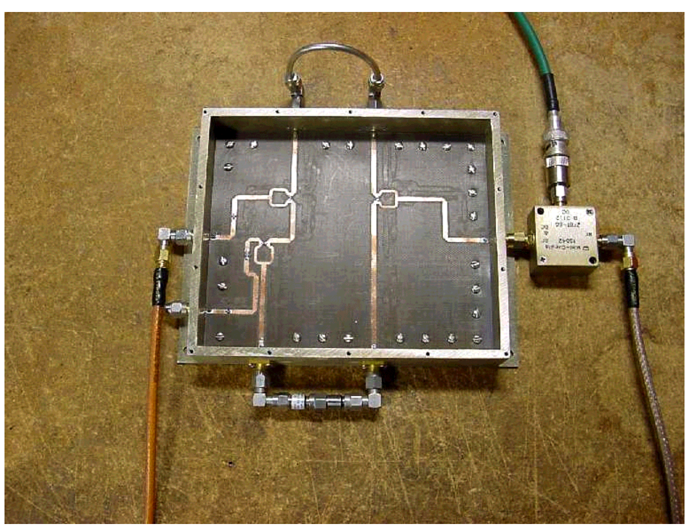

Fig.9. Photograph of the IIR notch filter

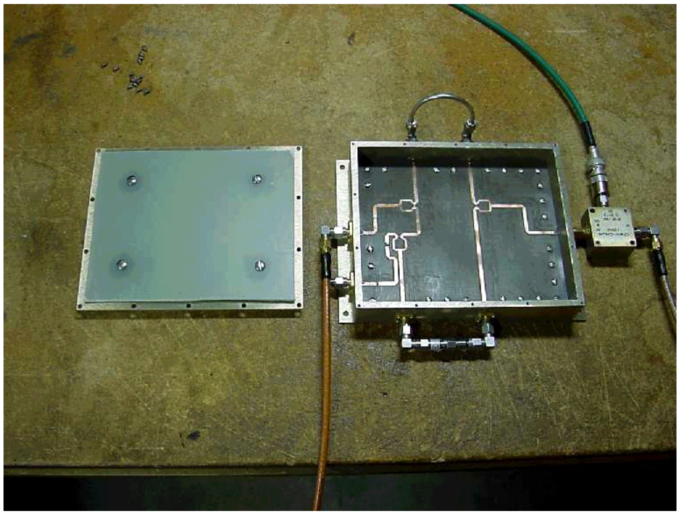

Fig. 10. IIR filter and cover with absorber material and G10 material

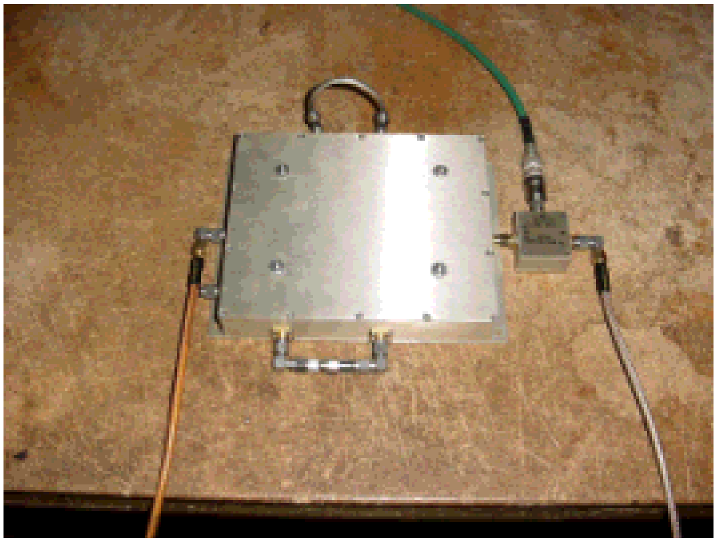

Fig. 11. Complete assembled IIR notch filter.

The measured results of the IIR notch filter are tested with the measured transfer functions between the 2-4 GHz stacktail momentum kickers and the 2-4 GHz betatron pickups. The results are shown in fig.12. The transfer functions are shown in blue, and the transfer function with the IIR notch filter is shown in red.

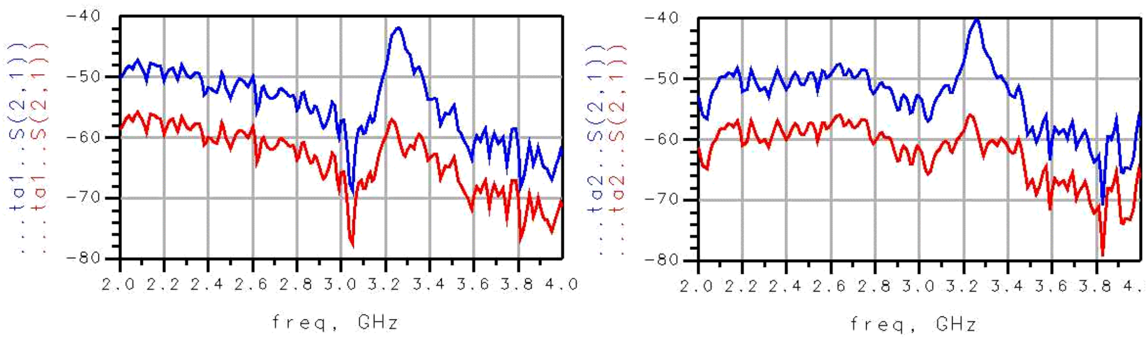

Fig. 12. Measured transfer functions with IIR notch filter

Measurements showing the change in notch depth versus DC bias is shown in fig.13. The filter was also tested for any changes versus temperature, but no significant changes were observed.

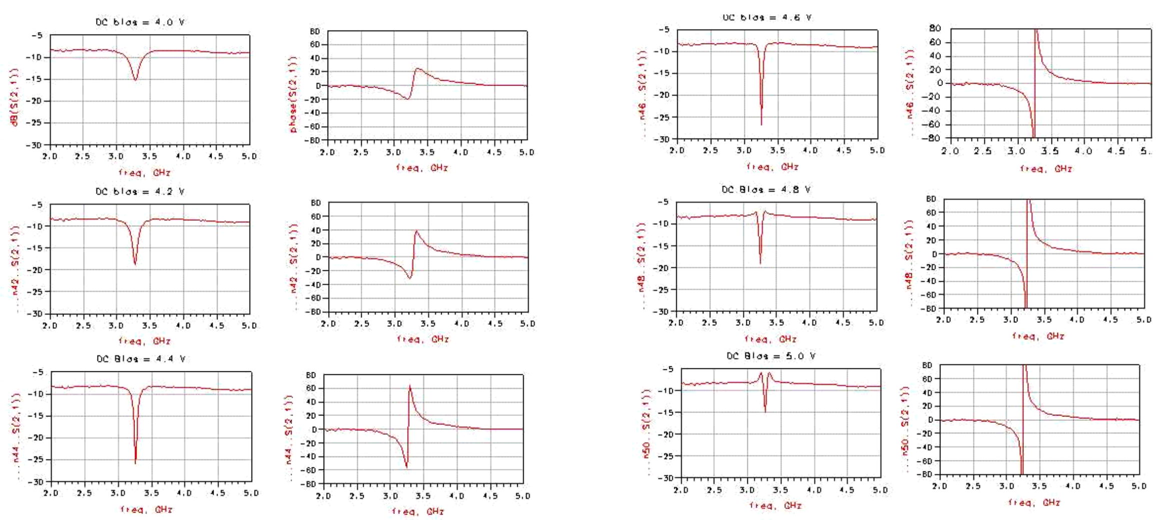

Fig. 13. Changes in notch depth versus DC bias voltage.